On the Nature of the Selective Fishing Action of Longline Gear

VERNON E. BROCK[1]

FISHERY BIOLOGISTS have, thanks to the magnitude of sampling provided by commercial fisheries, a better quantitative understanding of the populations with which they are concerned than do biologists interested in the quantitative aspects of other marine organisms. However, fishery biologists must be aware of bias that may be introduced by the sampling mechanism, the fishing apparatus. Fishing gear may be more effective in the capture of fish of some sizes or in some areas or seasons. If the nature of the bias is known allowance can be made for it, and its character may supply additional information on the population of fish.

Longline gear, as used for tuna fishing, characteristically takes the larger tuna. It is presently used to harvest a major portion of the world's catch of tuna, especially yellowfin tuna, *Thunnus albacares,* and bigeye tuna, *Thunnus obesus,* from the tropical waters of the Atlantic, Pacific, and Indian oceans. It is apparently the only method useful for the harvest of these species and, largely, of the albacore, *Thunnus alalunga,* in the open ocean far from land.

The present paper is concerned with a hypothesis regarding the basis for the selection of larger fish by longline gear based on the fish schooling theory of Brock and Riffenburgh (1960), together with a discussion of the relationship between availability of fish to longline gear and the age or size composition of the stock.

Only the relationship between yellowfin tuna and longline gear is considered in any detail. While the conclusions reached for this species may be applicable to others, there are certain difficulties involved in further comparisons. The lack of any substantial surface fishery for bigeye tuna makes any comparisons of the character of the catches between fishing methods difficult for this species. Albacore seem to be differentially distributed by size, and skipjack (*Katsuwonus pelamis*) are taken too infrequently by longline to provide useable data. Skipjack catches by longline are possibly analogous to catches of small yellowfin by the same gear.

Bluefin tuna (*Thunnus thynnus*) has not been considered; the occurrence of this species in temperate waters, subject to a variety of changes in the depth of the mixed layer, and its ability to live in both tropical and temperate marine environments, complicate any analysis. Schooling of large bluefin tuna may occur primarily for reproductive purposes.

ACKNOWLEDGMENTS

I wish to thank Mrs. M. L. Godfrey and other staff members of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii, who made a special effort in organizing IBM cards containing data on longline catches for machine computation, and Dr. R. H. Riffenburgh, who supervised the programming of a computer and made the tests of the significance of the differences in lengths of yellowfin taken solitarily, in pairs, or in runs of higher numbers.

DESCRIPTION OF LONGLINE GEAR

Longline gear is a floating or drifting fishing device which takes fish by hooking and is made up of a horizontal line, to which are attached droppers ending in baited hooks. While there are modifications of the basic plan, these are not important in terms of the present analysis. Shomura and Murphy (1955) described one of the gear designs employed by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii, as follows:

One unit of gear, called a basket, has 1,260 feet of mainline and six 88-foot branch lines (droppers) attached to the mainline at 30-fathom intervals. Several baskets are joined to make up

[1] U. S. Bureau of Commercial Fisheries, Honolulu, Hawaii. Manuscript received May 12, 1961.

Now, Biological Laboratory, Washington, D. C.

a set, the entire set being buoyed with floats at basket junctures and at the ends. Fishing at subsurface levels is accomplished by using 10-fathom lines between mainlines and floats and by setting the mainline slack so that it will sag in the water. To this end, the 1,260 feet of mainline is set in about 900 linear feet.

With this gear the minimum fishing depth is 148 feet and, of course, the droppers midway along the mainline between the floats would settle much deeper than this.

SIZE CHARACTERISTICS OF YELLOWFIN TUNA TAKEN BY LONGLINE, PURSE SEINE, AND LIVE-BAIT FISHING

Yellowfin tuna taken in the central Pacific by longline gear (Fig. 1*a*) were caught during the course of experimental and exploratory fishing by the Bureau of Commercial Fisheries. While the lengths range from 40 to 175 cm., the bulk of the fish exceed 120 cm. Figure 1*b* shows a percentage length frequency distribution of yellowfin tuna landed from the eastern Pacific (Hennemuth, 1961: table 1) by live-bait and purse seine fishing. While the lower length limit is about the same for both distributions, the largest sizes taken only infrequently by live-bait and purse seine fishing are about the same as the modal size taken by longline gear.

These distributions of lengths of fish taken by purse seine and live-bait fishing and by longline gear are typical for these fishing methods. Moore (1951) illustrates similar distributional patterns for yellowfin taken by longline and sold in the Honolulu market. Yabuta and Yukinawa (1959) give similar patterns of length distribution for fish taken in the western Pacific by this gear, as does Mimura (1958) for the Indian Ocean. Wilson and Shimada (1955) reported catches of large yellowfin by longline in the eastern Pacific; Mais and Jow (1960) reported on additional experimental longline fishing trials in the eastern Pacific, which also took large tuna, although not as large as those reported by Wilson and Shimada.

While purse seining for yellowfin tuna is largely confined to the eastern Pacific, a small live-bait tuna fishery for yellowfin off Japan takes fish of the sizes characteristic for this fishing method in the eastern Pacific (Yabuta and Yukinawa, 1957), and, from my observations, occasional catches taken by this method in Hawaii are composed of small and medium size fish.

POSSIBLE FACTORS AFFECTING SIZE OF YELLOWFIN TAKEN BY VARIOUS TYPES OF FISHING GEAR

Successful purse seine and live-bait fishing depend upon fish being in schools, and ordinarily upon their being evident on the surface of the water. Schooling fish may not be essential for successful longline fishing; in any event, the gear is ordinarily set without any surface evidence of fish.

The pattern of length distribution found in the purse seine and live-bait fishing catch could be attributed to selection against the smaller sizes ($<$ 50 cm.) by the fishermen and to decreasing abundance of the larger sizes through the effects of both fishing and natural mortality. Comparing length distribution of the central Pacific longline catch with that of the eastern Pacific surface fishery suggests that the former fishing method may be ineffectual for smaller fish. However, there exists a difference in the fishing grounds which may reflect some differences in population structure. In addition, the longline gear fishes at some depth; the other two methods depend upon schooling fish located by signs evident at the surface of the sea. The fish available to longline gear are called the "deep swimming tunas" in fisheries literature (Murphy and Shomura, 1955); they are presumed to be large in contrast to the smaller surface-dwelling fish.

Brock (1959) pointed out that areas which sustained large surface yellowfin tuna fisheries were located on the eastern margins of the tropical Atlantic and Pacific oceans, where the mixed or surface isothermal layer was relatively shoal. For the central and western Atlantic and Pacific and all of the Indian Ocean, where the mixed layer is fairly deep, only longline gear seemed to be effective.

Both purse seine and live-bait fishing depend on surface evidence of schooling fish. Where the isothermal surface layer is deep, schools may appear at the surface less frequently, thus reducing the effectiveness of these methods. Addi-

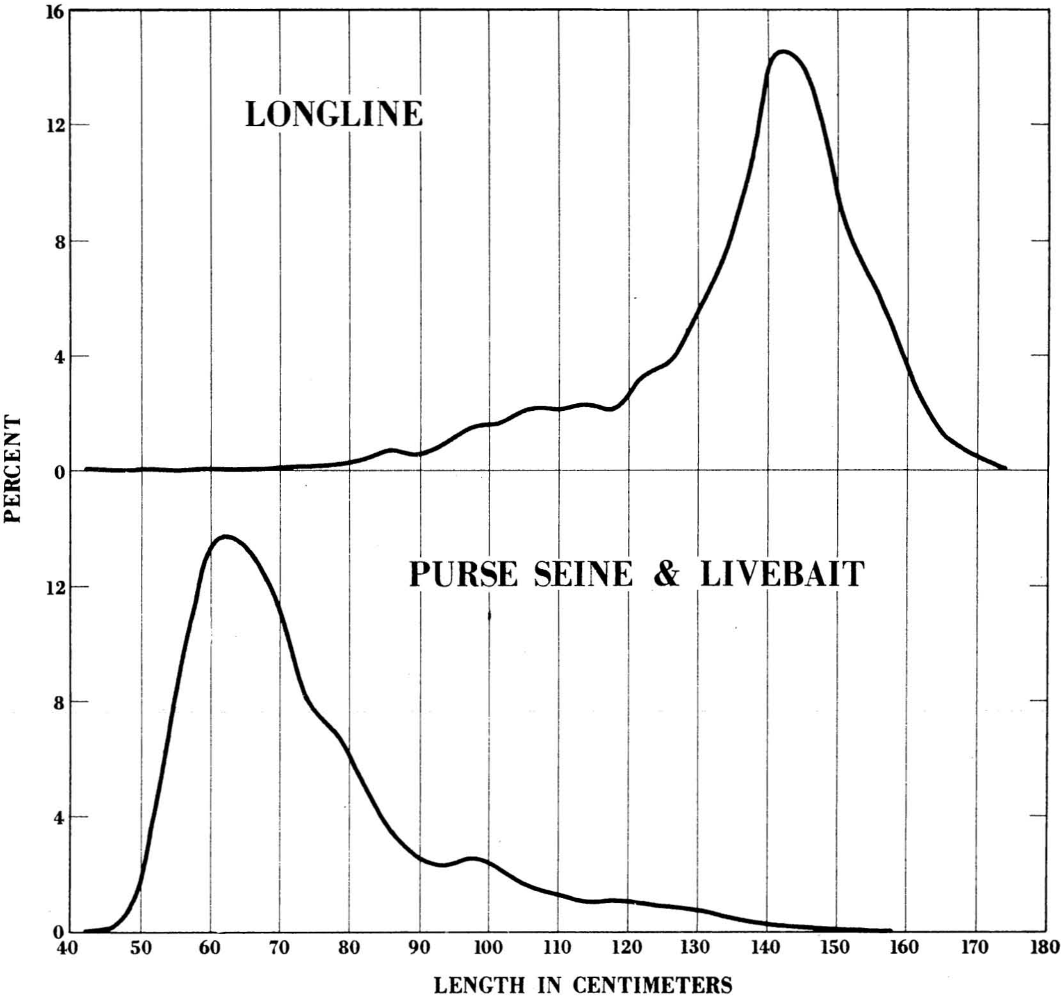

FIG. 1. *a,* Percentage length frequency distribution of yellowfin tuna taken by longline gear in the equatorial central Pacific. *b,* Percentage length frequency distribution of yellowfin tuna taken by both live-bait and purse seine fishing in the eastern tropical Pacific.

tionally, if larger fish tend to form smaller schools, or no schools at all for the largest sizes, the failure of fishing methods dependent on schooled fish to take larger sizes would follow. Conversely, longline gear should be most effective for scattered fish for reasons which will be given.

It may be pertinent, at this juncture, to define a fish school. A number of definitions have been suggested, which are discussed in detail by Breder (1959). A rather simple definition will suffice here. A school is two or more fish of the same species which respond to the others by swimming as a group. The response is assumed to be effected by vision; hence, the distance among fish within a school is less than the visual range, usually much less.

FISH SCHOOLING AND THE SIZE SELECTIVITY OF LONGLINE GEAR

If it is assumed that the number of fish in an average school is some inverse function of fish size, the low proportion of small yellowfin tuna in longline catches would be an expected consequence if longline gear was less effective in catching fish which were schooled than those which were not. Brock and Riffenburgh (1960) show that the anticipated encounter ratio of a predator for schooled or scattered prey of some number is

$$N_e = \frac{r^3 N_f}{\left[r + c \sqrt[3]{\frac{3 N_f}{4 \pi}} \right]^3} \quad (1)$$

where r is the visual range of the predator, N_f the number of prey, and c the average distance among individual fish in a school of N_f prey.

Equation (1) expresses the ratio of the visual densities of scattered and schooled fish. It would also express the ratio of encounter by scattered or schooled predators with some fixed number of prey, where N_f is the number of such predators and c the average distance among fish in a school of predators.

It contains three variables: (1) the visual range, which is a function of water clarity; (2) the number of schooled and scattered fish; (3) the space occupied by each fish in the school. If the visual range substantially exceeds the distance among fish in a school, then a school will scout through a substantially smaller volume of water than will an equal number of scattered fish, because the visual ranges of a large part of the schooled fishes overlap; this is not true for the scattered ones. For large schools, in clear water, the encounter ratios may range from hundreds to thousands in favor of the scattered fish. These relationships are illustrated in Figures 2 and 3.

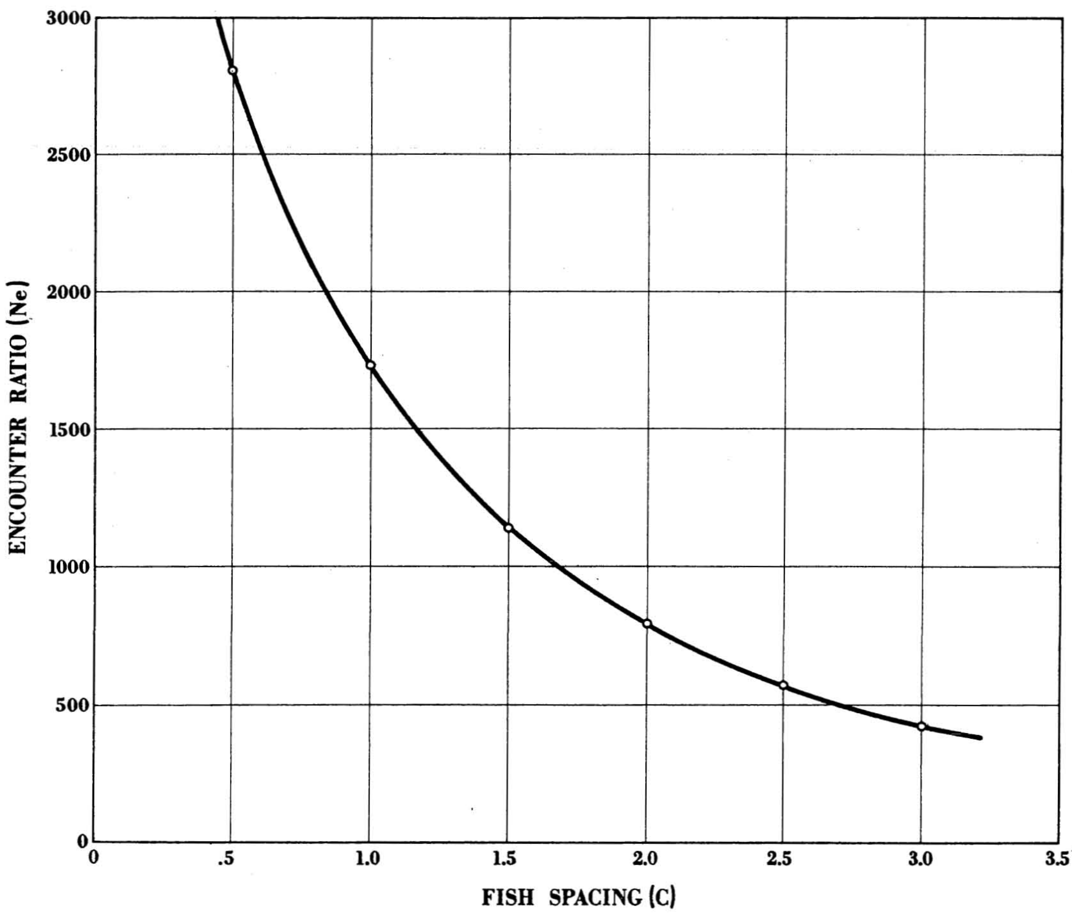

FIG. 2. Effect of increase in distance between fish in a school on the encounter ratio.

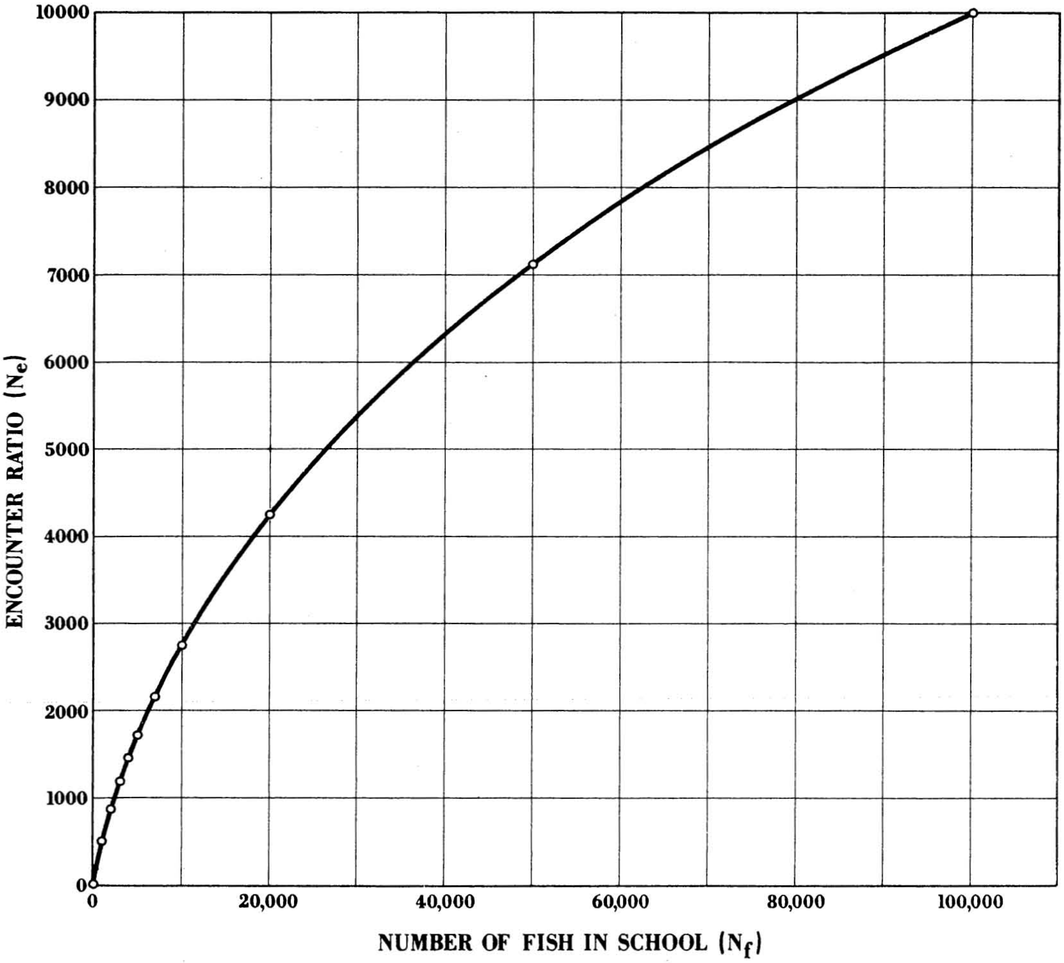

FIG. 3. Effect of increase in the number of fish in a school on the encounter ratio.

Figure 2 is a plot of the ratio N_e, the encounter ratio, against c, the distance among fish in the school. Visual range is assumed to be 25 meters and school size is taken at 5,000 fish. The increase of the encounter ratio with a reduction in the spacing (c) among fish in a school—as compared to an equal number of scattered fish—is apparent. This is to be expected, for the fish in a school approach the condition of scattered fish as a limit as the spacing among the schooled fish approaches the visual range. At this point, by definition, the school ceases to exist. If the spacing among schooled fish were a function of fish length, the relationship shown by the figure would suggest that schooling may be less effective for large fish than for smaller ones.

Figure 3 illustrates the effect on the encounter ratio of an increase in the number of fish in a school, assuming r equals 25 meters and c equals 1 meter. The encounter ratio is, of course, determined by the particular values assigned to r, c, and N_f, if the relationship postulated in equation (1) is valid. While the values selected are arbitrary, they are not unreasonable, except possibly in the magnitude of some of the bigger schools.

A school will scout a larger volume than that scouted by an individual fish, but less than that scouted by an equal number of scattered fish.

However, on the occasion of a school encountering a set of longline gear, a probability exists that if one fish should be captured from the school, additional fish will be captured thereafter. If the movement of the school is random and confined within a given depth, a likely situation in the tropics due to the rapid cooling of water with depth below the thermocline, the probability of hooking additional fish from the school may be roughly estimated in the following way.

If a fish should be taken on the jth hook of a set of longline gear, for the ith hook there will be a component of P of the form

$$P = \frac{\pi (r+r')^2 h_{1i-j1} K}{\pi (h_{1i-j1})^2 d}$$

and, summing for all i hooks and simplifying, we obtain

$$\sum_{i=1}^{n} P = \frac{(r+r')^2 K}{d} \sum_{i=1}^{n} \frac{1}{h_{1i-j1}} \qquad (2)$$

where h_i is the distance from the first hook taken to successive hooks ($h_1, h_2, h_3 \ldots h_n$), d the depth of water in which the fish may be expected to range, r the visual range, r′ the radius of the school, and K a factor with values between zero and one expressing the likelihood of a fish biting a baited hook.[2] An estimate of the probability of taking at least one additional fish was computed on the basis of a school of 2,000 fish with the values for equation (2) used in Figure 2, and a K value of one, a hook spacing of 54.86 meters (30 fathoms), and an isothermal layer, in which the fish occurred, 150 meters thick.

$P = .7382$ for 18 hooks, which would imply that additional fish may be hooked in three out of four sets of the gear where a school of the dimensions assumed here encounters a set of this number of hooks. Considering the possible high values of N_e, additional fish taken from schools may have relatively little effect toward increasing the catch from schooled as compared to scattered fish; from a school of 2,000, some 884 fish would have to be taken to cancel the effect of schooling on the basis of the school dimensions and visual range assumed in this example. Models with increased spacing among the schooled fish or with reduced visual ranges would reduce the effect of schooling; the assumed visual range is conservative for the areas where longline fishing is done. The example does imply, however, that runs of fish may be expected occasionally when a school encounters a set of longline gear, and that is the reason for presenting it.

It has been suggested that the number of fish in a school may be, on the average, an inverse function of the size of fish, with the largest fish occurring either in very small schools or not schooled at all. Accepting this assumption, it has been further hypothesized that the fishing efficiency of longline gear would be inversely related to the degree of schooling. If these are both true, then the longline catch should be composed of a disproportionate number of nonschooled fish or of fish from small schools. However, a probability exists for the capture of several fish from a school, and it is reasonable to assume that this probability is some function of school size.

If both the assumptions and the reasoning based on them are valid, it then follows that the mean size of fish taken by longline gear occurring in pairs or in larger groups on adjacent hooks should be less than that of the solitary hooked fish, and the greater the number of fish in a group the less their average size.

If such a size difference between grouped and solitary fish on longline gear does not exist, then, aside from the possibility of some artifact in the data, the hypothesis erected in this paper and briefly summarized above should be rejected. On the other hand, the existence of such a size difference would constitute evidence of the validity of the hypothesis, lacking alternate possible causes for this difference. It would also, thereby, constitute evidence for the validity of the fish schooling theory of Brock and Riffenburgh, since a pattern of size differences of this kind for longline gear is predicted by the theory.

Longline catch data obtained by the Bureau of Commercial Fisheries in the central Pacific

[2] In the case where $(r+r')^2 > h_{1i-j1}d$, equation (2) cannot be interpreted as a simple probability.

for the past several years were examined for evidence of a difference in the size of fish taken on adjacent hooks as compared to those not so taken. The results are given in Table 1.

The significance of the mean difference in length between solitarily hooked fish and all the fish hooked may be estimated by the Bienaymé-Tchbycheff Inequality. While the use of this inequality does not require any assumption of normality of the distribution of fish lengths, it does assume that the mean and the variance of the population are known. Since the sample is large (4135), it was assumed that the mean and the variance of all fish measured would adequately approximate those of the population.

$$\Pr\left[\left|\bar{x}-\mu\right|>e\right] \leq \frac{\sigma^2}{Ne^2} \qquad (3)$$

If the probability of deciding that $\bar{x}$ is different from μ when it is in fact not so should be taken to be 0.01, then

$$\frac{\sigma^2}{Ne^2} = \frac{389.52}{3192e^2} = 0.01, \text{ from which}$$

$$e = 3.49$$

For these data, $\bar{x} = 138.1$ and substituting this in the left side of (3), we have: $\bar{x} - 130.7 = 7.4 > 3.49$.

The probability given in (3) is seen to be less than 0.01; hence the difference between the solitary fish and all fish is significant.

If an assumption of normality of the distributions of fish length for each of the four groups is made, both the analysis of variance and the *t*-test indicate a highly significant difference among the groups.

The assumption that runs or pairs were invariably associated with catches from schools and that solitary fish taken were not from schools is obviously not completely true; pairs or groupings of higher numbers can occur by chance and it is at least possible to catch only a single fish from a school. The effect of chance groups and of the capture of single fish from a school would be to reduce the differences in size between the solitary fish and pairs or runs of higher numbers.

Through the application of simple probabilities, the number of fish that might be expected to be hooked in groups or individually was computed on the basis of the following assumptions.

1. The fish were randomly distributed and not schooled.
2. Fish were not caught simultaneously.
3. The catch rate was uniform at 6 fish per 100 hooks, which is a higher average rate than that for the catches in Table 1, and the gear set had 100 hooks.
4. Only a single species, yellowfin tuna, was considered in the computation, because the inclusion of other species would reduce the number of pairs and larger groups as compared to solitary fish.
5. While the end hooks on the set of gear were regarded as being available for fish, the computation of groups based on their occupancy was not made; this would also reduce the proportion of groups as compared to solitary fish.
6. The likelihood of a fish taking a hook was assumed to be the same for all unoccupied hooks.

Obviously the first fish hooked is solitary; the next fish may make a pair by taking a hook on

TABLE 1

MEAN SIZE AND NUMBER OF FISH HOOKED SEPARATELY OR IN GROUPS ON LONGLINE GEAR

NO. YELLOWFIN HOOKED SEPARATELY OR ON ADJACENT HOOKS	SAMPLE SIZE	MEAN WEIGHT (pounds)	MEAN LENGTH (centimeters)	VARIANCE (length)
1	3197	113	138.1	411.70
2	712	102	133.6	363.87
3	169	86	126.4	346.49
4	57	83	124.7	443.48
	4135			

TABLE 2

COMPUTED DISTRIBUTION OF FISH HOOKED FROM RANDOMLY SCATTERED INDIVIDUALS AND AN OBSERVED DISTRIBUTION OF THE FISH HOOKED ON LONGLINE GEAR

NO. YELLOWFIN ON ADJACENT HOOKS	SAMPLE SIZE		DIFFERENCE BETWEEN COMPUTED AND OBSERVED
	Computed	Observed	
1	3919	3197	—722
2	125	712	587
3	58	169	111
4 and over	33	57	24
	4135	4135	

either side of the first fish or may take another hook elsewhere.

For each additional fish caught there are certain limited numbers of possibilities of forming pairs or larger groups. Some of these are mutually exclusive, depending upon the particular arrangement of hooked fish at that time; and the sum of the probabilities for each of these, together with the probability of taking a hook apart from those with fish, must equal one. However, by setting up all possible combinations until six fish were caught, the basis for the distribution given in Table 2 was computed. It is obvious that—on the assumption that the fish were all taken from a randomly distributed population—the agreement is very poor between the numbers of fish hooked solitarily or in groups and the numbers of fish actually caught solitarily or in groups.[3]

The comparison given in Table 2 would imply that fish in groups occurred more frequently than would be anticipated if the distribution of the fish was random. It would strengthen the inference that many of the fish taken in groups were from schools. This is in agreement with the conclusions of Murphy and Elliot (1954), who, by the examination of the frequency of "runs," found some evidence for schooling in yellowfin catches taken by longline gear.

While the comparison given in Table 2 may provide some measure of the proportion of solitary fish occurring in groups, and hence an estimate of the contamination of groups formed by schools by adjacent fortuitous captures of solitary fish, the information is not adequate to provide a basis for adjusting the mean lengths of each of the groups; the reverse contamination of the solitary fish category by captures of single fish from schools has not been estimated. I can see no practical way of making such an estimate.

DISCUSSION

The mechanism of size selection of yellowfin taken by longline gear suggested here, that of schooling by fish size, if valid, has some interesting implications in regard to the magnitude of yields that may be anticipated at various fishing intensities. The availability of fish for a longline fishery may, on this basis, depend primarily upon the magnitude of that fraction of the population which is not schooled or is in small schools. In contrast, the efficiency of some other fishing methods for tuna, such as purse seining and live-bait fishing, depends primarily on the occurrence of fish in schools near the surface and larger than some minimum size. These fishing methods presumably would take fish before they were available to longline gear.

The relative fraction of the population available to the methods effective for schooling fish, as compared to those effective for scattered fish, would depend upon the pattern of growth and mortality.

Since fish are initially available to those methods effective for schools, a heavy fishing mortality for schooling fish would certainly re-

[3] The lack of agreement is sufficient between the "computed" and the "observed" to justify the assumption of a significant difference here without a formal statistical test.

duce the population available for longline fishing. This situation would be true regardless of the validity of the hypothesis proposed here regarding the mechanisms of catch selection by these fishing methods.

If mortality rates are uniform and high for the stock being fished, a high catch rate by longline gear suggests that fish of schooling sizes may be abundant enough to afford greater yields than those obtainable by longline fishing. This would be less true if mortality rates were much lower, especially for the medium-sized, rapidly growing fish than for the oldest fish.

To illustrate the relationship between longline catch and the population of fish whence the catch came, the distribution of the weight of a hypothetical population in terms of age is shown in Figure 4, together with the longline

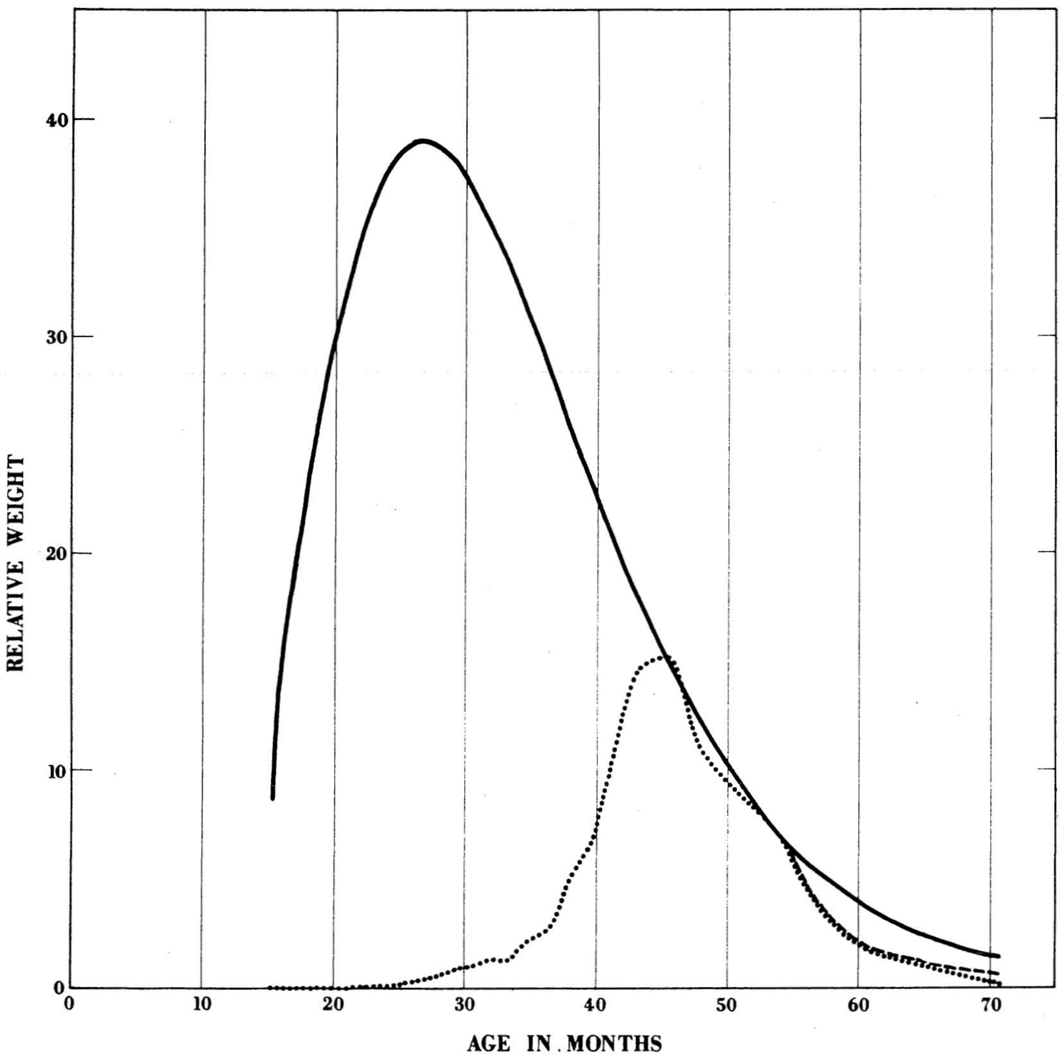

FIG. 4. Weight distribution for a hypothetical population and for fish taken by longline with identical mortality rates. The hypothetical population is shown by the solid line and by the dashed line (which is explained in the text). The dotted line is the age-weight distribution of yellowfin taken by longline gear in the central Pacific.

catch data shown in Figure 1*a*, also transformed into a plot of weight against age.

The weight–age relationship of the hypothetical population was computed as follows:

The longline catch data depicted in Figure 1*a* were transformed into a "catch curve" by converting length classes into age classes and plotting the age frequency curve on a semi-logarithmic basis.

The transformation of length into ages was done by using the von Bertalanffy equation of growth in the form

$$t = t_o - \frac{1}{k} \ln \left(1 - \frac{L_t}{L_{oo}}\right)$$

where t is the age at length L_t, K a constant, and t_o a time constant. The values for K, L_{oo}, and t_o were estimated from the growth rates for yellowfin tuna given by Moore (1951).

Four of the age classes following the modal class approximated a straight line, the slope of which was taken as an estimate of the mortality rate of the exploited stock. The terminal age classes did not fit this line. Current work on the growth of bigeye tuna by Richard Shomura (personal communication) suggests that for this species a differential mortality by sex may occur for the largest sizes, with the females dying before the males. Assuming a differential mortality rate by sex for the largest yellowfin, an adjusted fit was made for the last four age classes on the basis that (1) the sex ratio was initially 1:1, (2) that half the remaining female fish died between ages of 54.15 months and 56.6 months, (3) that all were dead thereafter. This adjusted fit is shown as a dashed line in Figure 4. The fit is surprisingly good. The weight of fish in each age class was obtained from the length-weight relationship

$$\text{Log weight} = -7.3548 + 2.9959 \text{ Log Length}$$

where length is in millimeters and weight is in pounds. Fish approximately 15 months of age and older were included in the hypothetical population.

This estimate of instantaneous mortality for the longline catch was $e^{-1.404}$, equivalent to an annual rate of .754.

The area of the longline catch curve is about 21 percent of that for the hypothetical population; this figure is an estimate of the fraction of the population available to longline gear. At an annual mortality rate of .374 the mode of the longline weight distribution and that for the hypothetical population would be in approximate coincidence.

I have no means of estimating the degree of agreement between the population of fish from which the longline catches were taken and the hypothetical population depicted in Figure 4. If the agreement is good, this is likely to be fortuitous; data for longline catches are taken from survey fishing efforts for a span of years and over a large area of the equatorial Pacific south of Hawaii. They are those catches for which both the size and specific hook position on the set of gear were recorded for each tuna taken. In addition, the assumptions of uniform recruitment, a uniform mortality rate, the growth rate used here, and equal availability of the four age classes older than the modal age class, would have to be satisfied to obtain a good agreement.

However, the pattern of weight increase with age is such as to suggest that longline gear, selectively taking the largest fish, would be an inefficient harvesting method except for tuna stocks subject to modest rates of mortality. It may also be difficult to realize yields approaching the maximum sustainable yield for stocks of yellowfin tuna by longline gear, since increases in the catch of fish would increase mortality rates with a disproportionate reduction in catch rates. If the weight of the landings is proportional to the weight of fish of the sizes available to longline gear, the effect in changes in mortality rates on catch rates may follow a pattern like that given in Table 3.

The values of Table 3 are based on the growth

TABLE 3

CHANGES IN AVAILABILITY OF FISH TO LONGLINE GEAR WITH CHANGES IN MORTALITY RATES

MORTALITY RATE %	CATCH RATE %
45	100
60	37.7
75	7.2

rates for Hawaiian yellowfin tuna (Moore, 1951) and the pattern of size selection of fish by longline gear for the catches shown in Figure 1*a*.

The purse seine method for fishing tuna is rapidly developing at the present time, a situation which may lead to the development of profitable fisheries in areas where this gear is not presently used. It may be suggested, however, that for those portions of the ocean where the isothermal layer is usually deep, there is not now available any fishing gear suitable for schooling fish when the fish may not ordinarily be at the surface of the sea. This may apply with greater force to the bigeye tuna, which is only occasionally caught at the surface anywhere.

SUMMARY

The selective capture of large fish by longline gear is described and various causes for this are discussed. One cause suggested is that small tuna are more highly schooled than large ones and, according to the schooling theory of Brock and Riffenburgh, the likelihood of capture on a longline would be greatest for scattered fish.

The probability of taking more than one fish from a school on longline gear after the school encounters the longline is shown to be good, depending upon the diameter of the school and the visual range of the fish.

If there is an inverse relationship between the fish size and the number of fish in a school and if the probability of a number of fish occurring on adjacent hooks is proportional to the size of the school, then the mean size of the fish hooked in a group should be inversely proportional to the number of fish in the group. This is shown to be true for longline catches made by the Honolulu Laboratory in the central Pacific.

The relatively low availability of schooled fish to longline gear is discussed, together with the probable effect of high mortality rates on the longline catch rates.

It is suggested that there are no fishing methods effective for schooling yellowfin where the schools are not present at or near the surface of the sea, and that schools are apparently uncommon in surface waters for the greater portion of the tropical Atlantic and Pacific and for all of the Indian Ocean, where the isothermal layer is deep. The possibility of an analogous situation for bigeye tuna is suggested for all tropical oceans.

REFERENCES

BREDER, C. M., JR. 1959. Studies on social groupings in fishes. Bull. Am. Mus. Nat. Hist. 117(6): 393–482, 28 figs., 10 plates.

BROCK, VERNON E. 1959*a*. The tuna resource in relation to oceanographic features. U. S. Fish and Wildlife Service Circular 65: 1–11, 15 figs.

——— 1959*b*. Tuna fishing methods and their application. U. S. Fish and Wildlife Service Circular 65: 12–16, 4 figs.

——— and R. H. RIFFENBURGH. 1960. Fish schooling: a possible factor in reducing predation. Jour. du Cons., Cons. Internat. Expl. Mer 25(3): 307–317.

HENNEMUTH, RICHARD C. 1961. Size and year class composition of catch, age and growth of yellowfin tuna in the eastern tropical Pacific Ocean for the years 1954–1958. Inter-Am. Trop. Tuna Comm. Bull. 5(1).

MAIS, KENNETH F., and TOM JOW. 1960. Exploratory longline fishing for tunas in the eastern tropical Pacific, September 1955 to March 1956. Calif. Fish & Game 46(2): 117–150.

MIMURA, K. 1958. Study of the fishing conditions of the yellowfin in the Indian Ocean, especially on annual differences of the hooked-rate and size composition. Rept. Nankai Reg. Fish. Res. Lab. 7: 59–71.

MOORE, H. L. 1951. Estimation of age and growth of yellowfin tuna (*Neothunnus macropterus*) in Hawaiian waters by size frequencies. U. S. Fish and Wildlife Service, Fish. Bull. 65: 133–149, 14 figs.

MURPHY, G. I., and K. C. ELLIOT. 1954. Variability of longline catches of yellowfin tuna. U. S. Fish and Wildlife Service, Spec. Sci. Rept. Fish. 119.

——— and R. S. SHOMURA. 1955. Longline fishing for deep-swimming tunas in the Central Pacific, August–November 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept. Fish. 137.

SHOMURA, R. S., and G. I. MURPHY. 1955. Longline fishing for deep-swimming tunas in the Central Pacific, 1953. U. S. Fish and Wildlife Service, Spec. Sci. Rept. Fish. 157: 1–70, 19 figs.

WILSON, ROBERT C., and BELL M. SHIMADA. 1955. Tuna longlining: results of a cruise to the eastern tropical Pacific Ocean. Calif. Fish and Game 4(1): 91–97.

YABUTA, Y., and M. YUKINAWA. 1957. Age and growth of yellowfin tuna (*Neothunnus macropterus*) in Japanese waters by size frequencies. Nankai Reg. Fish. Res. Lab. Rept. 5: 127–133.

——— and ——— 1959. Growth and age of the yellowfin tuna (*Neothunnus macropterus*) in the equatorial Pacific. Study of length frequency distributions—1. Rept. Nankai Reg. Fish. Res. Lab. 11: 77–87, 7 figs.